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“TELETRACK” – A special effect

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Summary

This report describes the theory of operation of a television special effects processor called Teletrack, which is broadly similar to a system developed by CBS[1].

The factors involved in the design of a Teletrack processor are outlined and the operation of two preferred forms is described in detail along with the special considerations required for operation on composite PAL signals.

Teletrack was the forerunner of a whole family of special effects processors, made possible by the flexibility and precision of digital signal processing. It was first used in the BBC Television Service in 1980, and is available in special effects equipment manufactured by Quantel Ltd.

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"TELETRACK" – A SPECIAL EFFECT

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"TELETRACK" – A SPECIAL EFFECT

R. Storey B.Sc., C.Eng., M.I.E.E.

1. Introduction

Teletrack is a system which periodically identifies and records the image of a moving object against a stationary background, creating a series of frozen images which display the object's trajectory. The effect was originally intended for use in sports coverage, where the action is shot using a stationary or "locked off" camera. Typical examples are a goal kick, a golf putt or a snooker shot as in Fig. 1. Experience has shown however, that it can also be used to provide interesting artistic special effects.

The system detects the position of a moving object in any television field by comparing the signal from that field with a signal from a stored reference field. Since the background is constrained to be stationary, any large differences between the two signals correspond to the position of the object in each of the two fields. A confusion may arise if the positions of a plain (undetailed) object overlap but this can be minimised if necessary by a suitable choice of stored reference field (see Section 2).

As the positions of the moving object are established, the corresponding images are written one by one into a re-circulating field store. The accumulated set of images can be displayed either as they are created or at the end of the Teletrack sequence, depending upon the system design.

In addition to these basic features, there are a number of refinements which would be useful from a production viewpoint. Firstly, the frozen images should be captured at selected, usually uniformly spaced, instants. The ideal spacing will normally be dependent upon the speed of movement and should therefore be adjustable to give the best artistic effect. Secondly, it should be possible to display the accumulated image path, with or without a 'frozen background' for as long as desired. Finally, it should be possible to display a track which decays with time, this can give a pleasing subjective effect since it indicates the direction of movement of an object.

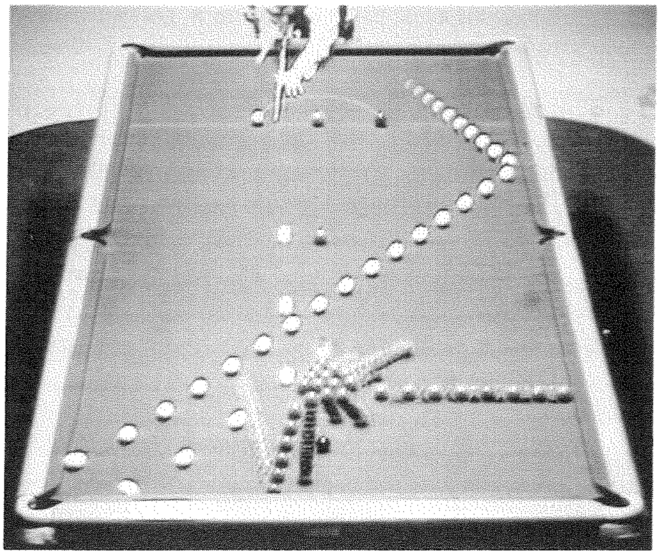

Fig. 1 – Teletrack effect

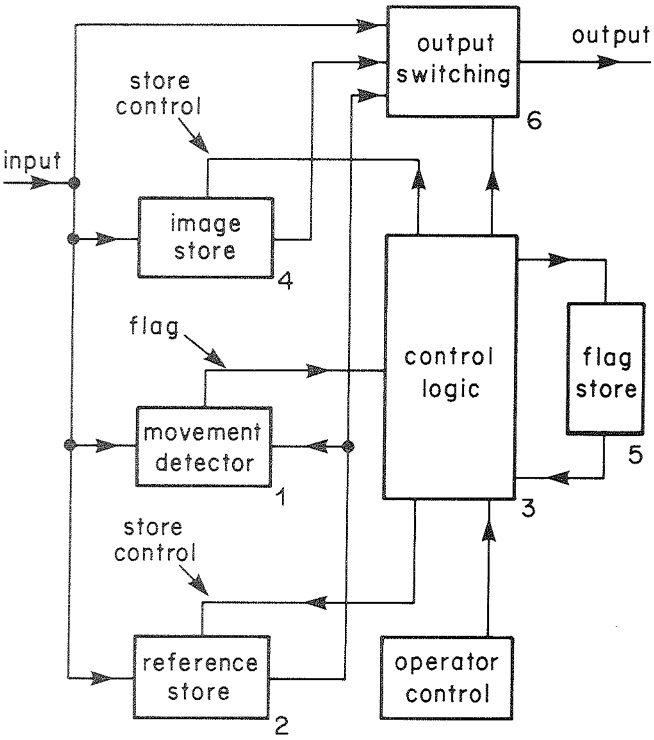

Fig. 2 – Teletrack block diagram

Teletrack therefore requires a means for accurately processing video signals and also a means for storing them for relatively long periods, without degradation. The required degree of accuracy dictates that the signal processing and storage must be digital.

2. Realisation of Teletrack

2.1. General

The basic requirements for the Teletrack effect are shown diagramatically in Fig. 2. A movement detector 1 identifies the positions of moving areas of picture by comparing the current input signal with a signal describing a "reference" field. The reference field signal is captured by a store 2 at the beginning of the Teletrack sequence.

Effective movement detection therefore requires that the signal describing the current background should not differ greatly from the corresponding reference-field signal. This means that the incoming background must be stationary. In addition, the reference-field signal must be continuously modified to prevent the occurrence of spurious movement detections, caused by changes of scene illumination and camera unsteadiness. This subject is discussed more fully in Section 2.3.

The movement detector output "flags" those parts of the input signal describing the image of a moving object. The flag signal is used by the control logic circuitry 3 to feed the moving object's image signal into a field store 4. The flag signals from successive updated fields (those fields in which a new image is captured) are recorded in a flag store 5 whose contents therefore describe the positions of each image in the accumulated image set.

The flag store output is used to control the keying of frozen images from the image store into the incoming picture signal by a switch 6 to form a Teletrack display. The reference store contents may be used to provide a background display at the end of a Teletrack sequence, allowing a frozen picture to be maintained after the input picture has changed.

Operation in colour can be achieved either by processing the luminance and chrominance components of the signal separately, or by processing the composite PAL signal with special consideration for the colour subcarrier.

The following section deals with the operation of the movement detector. Section 2.3 outlines the factors involved in deciding which of the many possible forms of Teletrack circuits to use. Sections 3 and 4 describe in detail the operation of two preferred forms of Teletrack processors and Section 5 discusses the problems posed by colour signals.

It is well known that a frozen picture of a moving scene must be generated from information corresponding to only one field. If a complete input picture (two successive fields) were used, the frozen picture would show an unacceptable picture-frequency flicker, caused by scene movement in the time separating the two interlaced field scans. The use of a single field does, however, result in the loss of vertical resolution, and necessitates formation of lines of the missing field by interpolation.

The frozen images displayed during the Teletrack effect are therefore generated from a single stored field. The reference signal used for movement detection can likewise be stored in a single field store, and may be used if necessary for movement detection in any field by using appropriate interpolation.

2.2. Movement detection

The position of a moving object is detected by comparing signals from two fields separated in time; one of these is the current input field and the other is a stored reference field.

The movement of an object during the time interval separating the two fields will give rise to two significant differences, one corresponding to the position of the object in the reference field and the other to its position in the input field. Both of these areas are identified by the appearance of a "flag" signal at the movement detector output. These "flag" signals are stored in a recirculating field store for future use.

The movement detector operates by subtracting a signal describing the reference field from the signal corresponding to the current input field (see Fig. 3). These difference signals will, under ideal

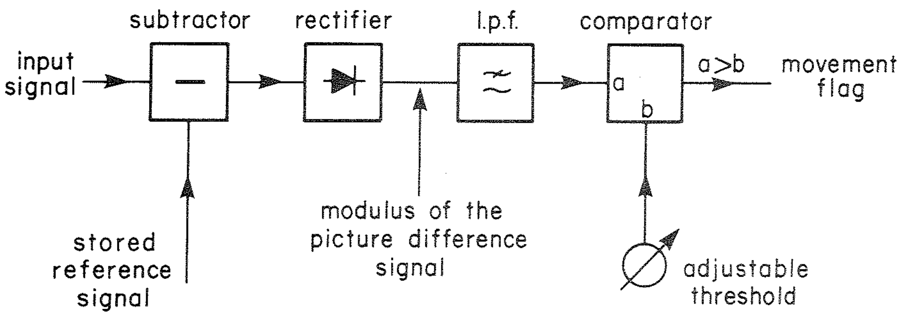

Fig. 3 – Movement detector

conditions, be polluted only by random noise or film grain. In a practical situation, they will contain other components; for example those caused by camera unsteadiness or gradual changes in scene illumination.

The problem of pollution, by noise and film grain can be largely overcome by spatial low-pass filtering[2,3] of the picture-difference signals. This technique gives an improvement because the movement components of the difference signal are characterised by low spatial frequencies, whereas the noise and grain components generally have a spectrum occupying the entire video bandwidth. A spatial low-pass filter therefore increases the "movement-to-noise ratio" and makes detection more certain.

Movement is detected by comparing the spatial filter output with an adjustable threshold; any signal which is above this threshold is deemed to be due to movement and any signal below the threshold is deemed to be noise. The adjustable threshold therefore controls the sensitivity of the movement detector and also allows a certain amount of protection against camera unsteadiness.

The problems caused by changes in scene illumination are a little more difficult to solve, but an attempt can be made, by exploiting the fact that overall luminance varies relatively slowly with time. The reference field can be modified to prevent the accumulation of an error due to this cause, and hence reduce the probability of a change in luminance being interpreted as movement. This subject is discussed more thoroughly in Section 2.3.

2.3. Choice of system

As mentioned earlier, the Teletrack effect can be realised in a number of different forms, each of which has advantages and disadvantages. The choice of system type is therefore dictated by performance requirements and cost, since a more versatile processor will generally be more expensive.

The factors involved in this choice are the source of the reference field for movement detection and whether the required series of images are accummulated in the same store as the reference field, or in a separate store.

The reference field can be either the first field of a complete Teletrack sequence, a conditionally updated first field, or it can be the "last processed field" (i.e. it can be updated each time a new image is captured in the image store).

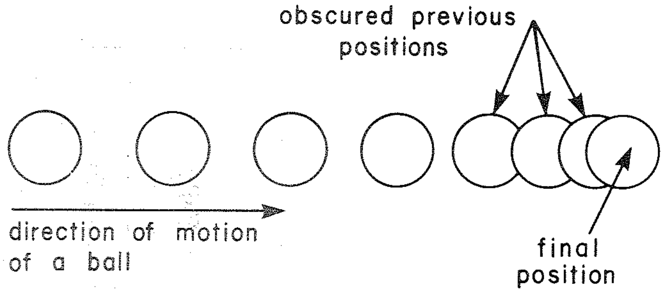

Fig. 4 – Normal obscuring

If the first field of a Teletrack sequence is used then, once the moving object has travelled far enough so as not to overlap its starting position, its later positions can be found uniquely, no matter what the speed of movement. The implication of this is that a new image can be made to overwrite an old one, as in Fig. 4, when the object's positions in neighbouring processed fields overlap. This is termed "normal obscuring".

The disadvantage of using the first field as a reference is that any gradual changes in scene illumination or camera position will cause an accumulating error in the picture-difference signal, leading to false movement detections. This problem can be overcome to a certain extent, by allowing the stored reference field to be modified by the incoming fields in areas where the movement detector has found no movement (i.e. a small picture difference).

If the stored reference field is updated by the incoming fields, regardless of the movement detector output, this constitutes a third approach, which is to use the last processed field. This option is very tolerant of scene illumination changes and spurious camera movements, but presents a problem during slow movement. If the positions of an object in neighbouring processed fields overlap, there is no way of identifying which part of the movement detector flag signal belongs to the later of the two fields. The recirculated flag signal can at best preserve the earlier frozen image at the expense of the later one. Old images will therefore obscure new ones, as in Fig. 5, making the final

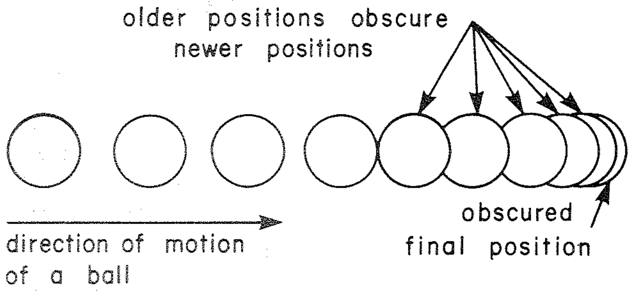
older positions obscure newer positions
direction of motion of a ball
obscured final position

Fig. 5 – Reverse obscuring

Table

	System Type		Storage Fields	Obscuring	Available Display Modes	Movement detection Failure
	Reference Store	Image Store				
A	First field reference	Shared	1	Reverse	Input scene + track or frozen scene + track	Failure during slow background movement or change of illumination
B		Separate	2	Normal or reverse	Input + track, frozen scene, frozen scene + track	Failure during slow background movement, or change of illumination
C	First field with updated back-ground	Separate	2	Normal or reverse	Input + track, frozen scene, frozen scene + track	No failure during slow background movement or change of illumination
D		Shared	1	Reverse	Input + track, frozen Scene + track	No failure during slow background movement or changes of illumination
E	Last processed field					
F		Separate	2	Reverse	Input + track, frozen scene, frozen scene + track.	No failure during slow background movement or change of illumination.

track appear back-to-front, which may be subjectively disturbing. This is termed "reverse obscuring".

2.4. Storage of frozen images

Frozen images may be stored in a separate, recirculating field-store or in the store used for the reference field. A shared image and reference store offers a reduction in overall cost, but does not permit the desirable "new-obscures-old" effect mentioned previously, to be obtained. This occurs because the reference field contains, in addition to the original image, all the images that have been stored during the Teletrack sequence. An additional shortcoming of the shared store approach is that it is impossible to display a frozen field at the end of the Teletrack sequence and add the track to it separately. The ability to display a frozen field and the track independently may be convenient from a production point of view.

Table 1 summarises the consequences of the various choices of reference and image stores.

From the Table it is evident that an updated reference and separate image store (option C in Table 1) gives the most versatile Teletrack processor. If, however, only one field of storage is to be used, the normal obscuring facility must be sacrificed. The reference field in this case should be updated regularly which is equivalent, if frozen images are stored in the reference store, to updating from the last available field (options D and E).

Sections 3 and 4 describe the implementation of option C and options (D and E) respectively.

3. Teletrack with separate reference and image stores

Fig. 6 shows a block diagram of a monochrome Teletrack processor which has a field store (17) for the reference field, a field store (13) for "frozen images" and a "flag" store (6) which records the past positions of the moving object. These stores are shown as recirculating delays with a total delay time of one field. In practice, the delays would need to have a duration of 312 lines in even fields and 313 lines in odd fields to give an overall delay of 625 lines during one picture period.

There are also three contol signals, an "initiate" control which prepares the machine to record a new track, an "update" control which appears for 1 field in N and thereby contols the frequency of generation of frozen images, and a "freeze" control which, in this circuit, displays the accumulated track held in store (13), keyed into a background supplied by the reference store (17).

The operation of this circuit is as follows:

At the beginning of a Teletrack sequence, the initiation control provides a logic 1, which clears the flag store via gate (5) and directs the current input field into the reference store via switch (16). During this time, new flags are prevented from entering the flag store by gates (2) and (4).

During the following fields the reference store is updated by the input signals in all areas, except those that are deemed to be moving by the movement detector (1). The necessary control signal reaches switch (16) via gates (9) and (15). A delay (3) compensates for the delay of the movement detector.

An image can be recorded by operating the update control for a full field, thereby allowing new flags identifying the position of the moving object in the current field to enter the flag store. At the same time the image store (13) takes the signal corresponding to the object's image, via switch (12) which is controlled by gate (4). During this field, the image of the object passes directly from input to output via switch (11) which is controlled by gate (7).

The frozen image will be displayed on all subsequent fields by the action of switch (14) and switch (11). These two switches route the output of the image store to the processor output when there is a recirculating flag, but no current indication of movement. This condition is detected by gate (7) and guarantees that the current object image will obscure the previously frozen image, should the two overlap. When the current image has moved far enough for there to be no overlap, the complete frozen image will be revealed, provided of course that there has been no update instruction. Note that by intercepting the control signal to switches (11) or (14), a track can be accumulated in the image store without being displayed. The movement track can then be made to appear at a later time if desired. Further frozen images will be recorded in the same way whenever the update control provides a logic 1.

The reference field will always contain an image of the object in its initial position, which will be protected by virtue of its own existence (in other words, it will create a movement signal which will instruct the reference store to recirculate). The movement-detector output will therefore generate

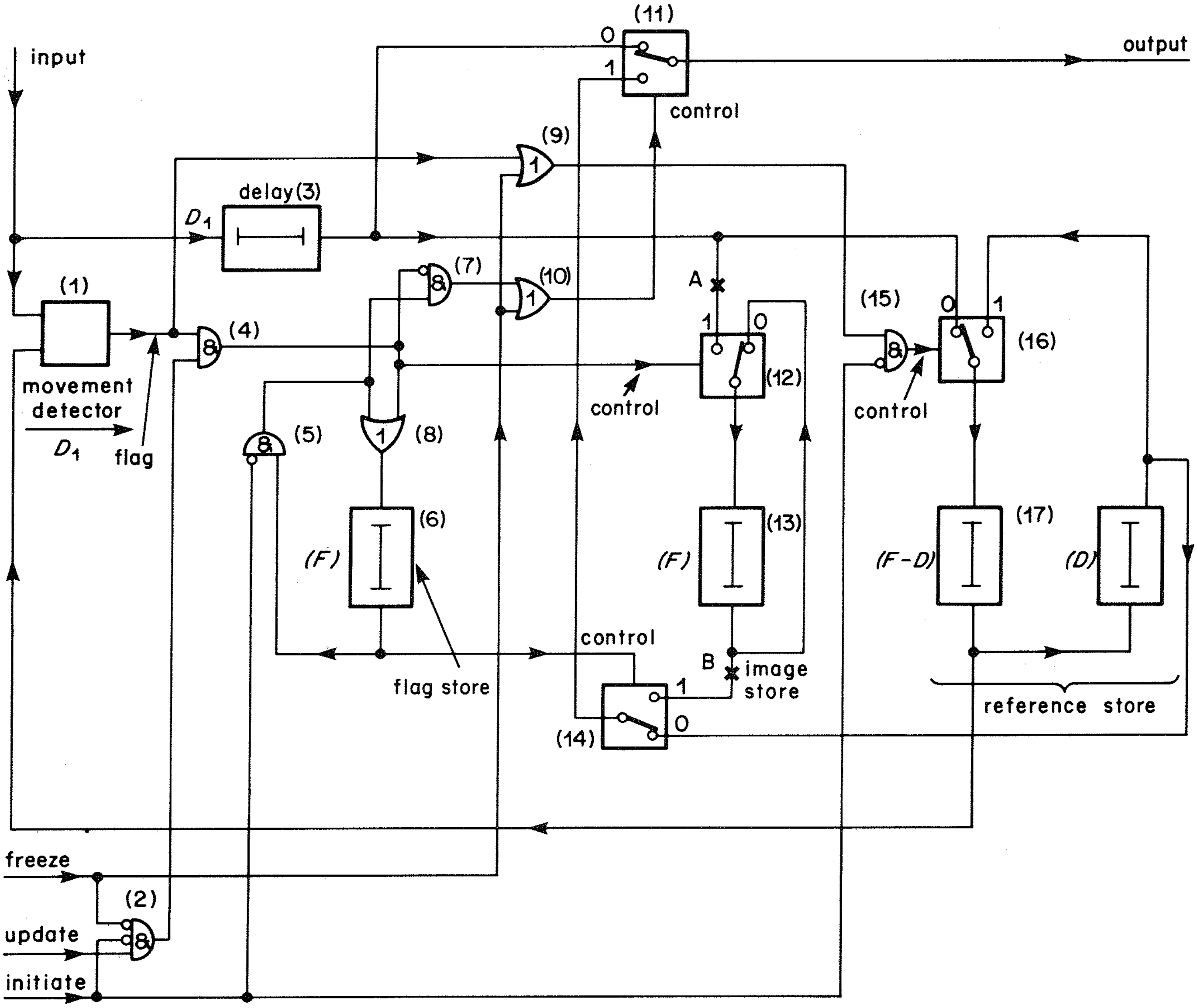

Fig. 6 – Block diagram of a Teletrack processor using separate reference and image stores

two movement signals, one in the object's current position, which will cause the image store to record a corresponding image, and one in the object's initial position. The latter signal will cause a new piece of background to be recorded in the image store during each updated field. The complete sequence will therefore consist of an accumulating set of images, the first one of which is replaced by current background during each updated field.

The Teletrack sequence is terminated by causing the freeze control to provide a logic 1, thereby preventing the creation of any new flags by gates (2) and (4) and forcing the image store to recirculate continuously. Gates (9) and (10) respectively cause the reference store to recirculate and the output of switch (14) to appear at the output of the machine via switch (11).

In this circuit, switch (14) is arranged to select the stored reference field in unflagged areas and the contents of the image store in flagged areas. Alternative modes of display are available. For instance, the accumulated track could be keyed into the stored reference field at any time by modifying the control signal to switch (14).

This arrangement can provide reversed obscuring by modifying the control of switch (12). It can accumulate a series of tracks by not initiating between freeze operations. By incorporating a " 2 bit" flag store it can display any one of four separate tracks (subject to no overlap).

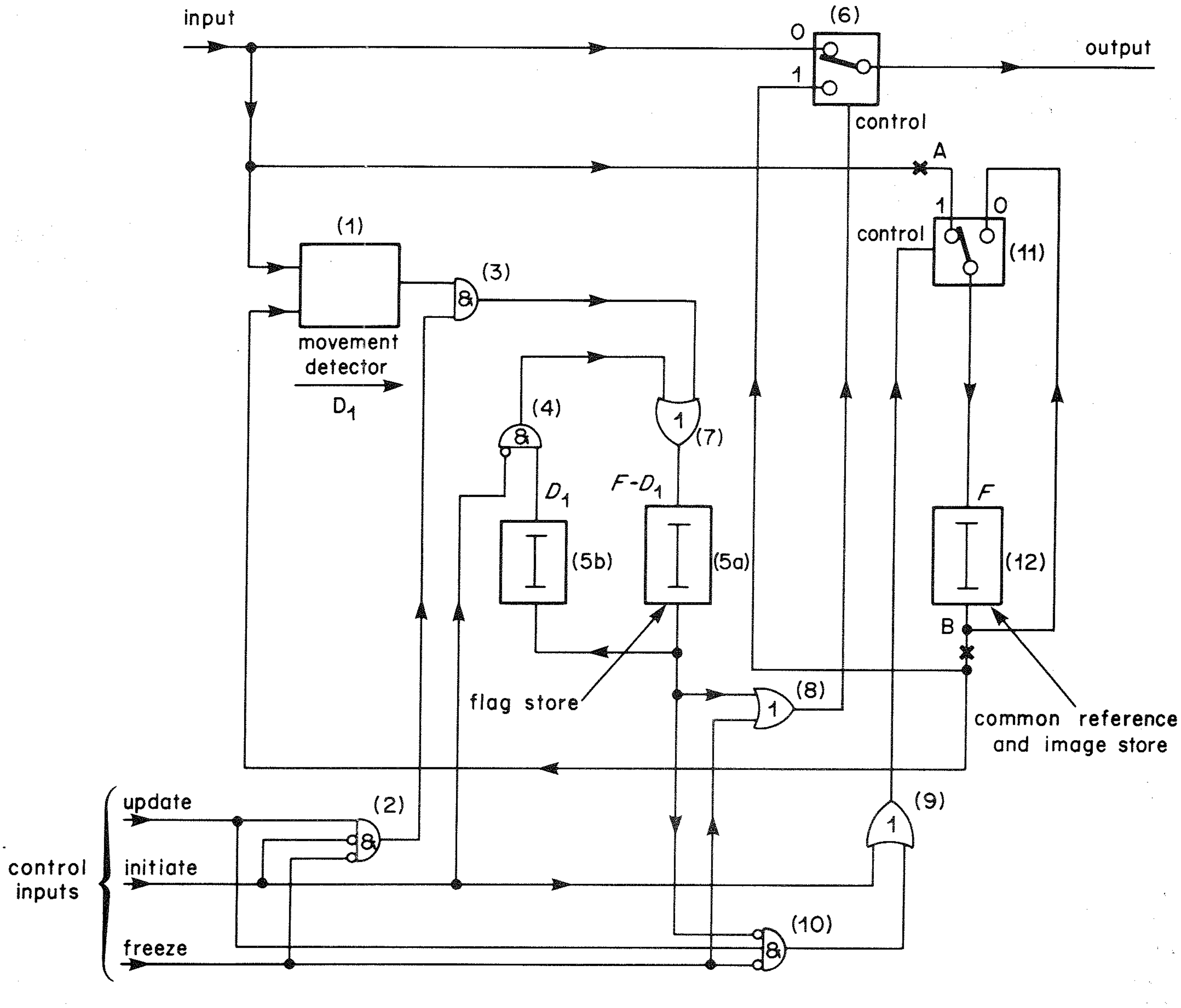

Fig. 7 – Block diagram of a Teletrack processor using shared reference and image stores

4. Teletrack with shared reference and image stores

Fig. 7 shows a monochrome Teletrack processor, using only one field store that combines the functions of reference-field and frozen-image store. Such an arrangement saves the cost of one field store, but gives a less versatile processor.

The operation of the arrangement shown in Fig. 7 is similar in many respects to that shown in Fig. 6.

The initiate control clears the flag store via gate (4) and fills the combined reference and image store with the incoming signal via switch (11) and gate (9), thereby discarding any previously stored images.

The reference store is updated with new background and moving object whenever the update control signal is a logic 1. When the update signal is made a logic 1, the movement detector produces two flag signals, one corresponding to the object's new position and the other to its position in the previous updated field. These two flag signals enter the flag store via gates (3) and (7).

During the following fields, the recirculating flag signal appears at the output of store (5a) and via gates (9) and (10) instructs the common reference and image store (12) to recirculate in flagged areas. The information which will be recirculated after the *first* operation of the update control will be the image of the object as it appeared in the updated field, and in addition a piece of background will be recirculated in the area that the object occupied in the initial field.

Note that since the reference signal must always contain the image of the moving object during the last updated field, it will not be possible to determine, during an overlap, which part of the flag signal refers to the new position and which part to the old position. The best that can be achieved therefore is to protect the frozen images as they occur. This implies that an old image will always obscure a newer one, resulting in the reverse obscuring effect mentioned earlier.

Operation of the "freeze" control inhibits the generation of new flags by the action of gates (2) and (3), and causes the contents of the combined image and reference store to be recirculated. Switch (6) selects the output of the field store and provides a frozen background with a recorded track, for display.

It should be noted that the final display can only be the frozen reference signal and track, or the current input signal with an accumulated track keyed in.

5. Operation on colour signals

Colour operation may be achieved by decoding the PAL or NTSC signal into its component parts, processing these in three linked Teletrack processors and recoding to give a PAL or NTSC signal at the output.

Alternatively, the composite signal may be processed, without explicit decoding, by modifying the colour subcarrier phase such that the image and reference stores contain information at a subcarrier phase corresponding to one field only. The colour phase of the input and output signals of the recirculating stores may then be modified to match that of the incoming signal where necessary. This latter technique guarantees that the information in the image and reference stores can be recirculated indefinitely, without the progressive degradation that occurs if the phase of the stored signal is modified on each recirculation.

5.1. Decoding to components

The first method of colour operation requires that the composite colour signal be decoded into luminance and chrominance components, *Y*, *U* and *V* for PAL. These component signals are then used as inputs for three linked Teletrack processors as shown in Fig. 8.

Movement detection is performed on the *Y*, *U* and *V* components separately, and a logic OR function is derived from the three separate flag signals. In this way, a moving object can be detected whether it is coloured or not.

The combined flag signal enters a common flag store which instructs the three Teletrack processors to capture and hold images simultaneously and in parallel. The processed *Y*, *U* and *V* signals are then encoded to give a composite colour signal at the output.

The recirculating image stores in the *U* and *V* processors can have a reduced capacity compared to the store in a *Y*, or a monochrome processor.

Impairments may be visible on the frozen parts of the output picture. These impairments occur whenever a frozen image is decoded in one phase of the PAL 8-field cycle (or NTSC 4-field cycle) and encoded in a different phase. The perceptibility of the impairments will depend upon both the update rate and in particular, on the effectiveness of the decoding.

The background signal is kept free from impairments by having a direct path which is used during the accumulation of a track or when the processor is not being used.

5.2. Processing by storing the composite signal

A processor which operates on the composite colour signal is merely a special case of the system outlined in the previous section, wherein the colour signal is not decoded into separate components, but is modified to give a fixed colour subcarrier phase in the processor. This means that the stored signals can be recirculated without the need to change their phase on each field, and the spatially aligned signals appearing at the movement detector inputs will have the same subcarrier phase. A block diagram is shown in Fig. 9.

The predictor converts the phase of the incoming subcarrier to that corresponding to, say, field 1 of the PAL 8-field cycle (or NTSC 4-field cycle). The Teletrack processor will therefore receive a picture signal whose subcarrier is effectively field locked, thus allowing the movement detector to operate correctly.

The subcarrier phase at the processor output is modified again by an inverse predictor which converts the subcarrier phase from that during field 1 to that of the current input field.

The image and reference stores must be capable of storing a composite PAL signal, sampled at a frequency above the Nyquist limit.

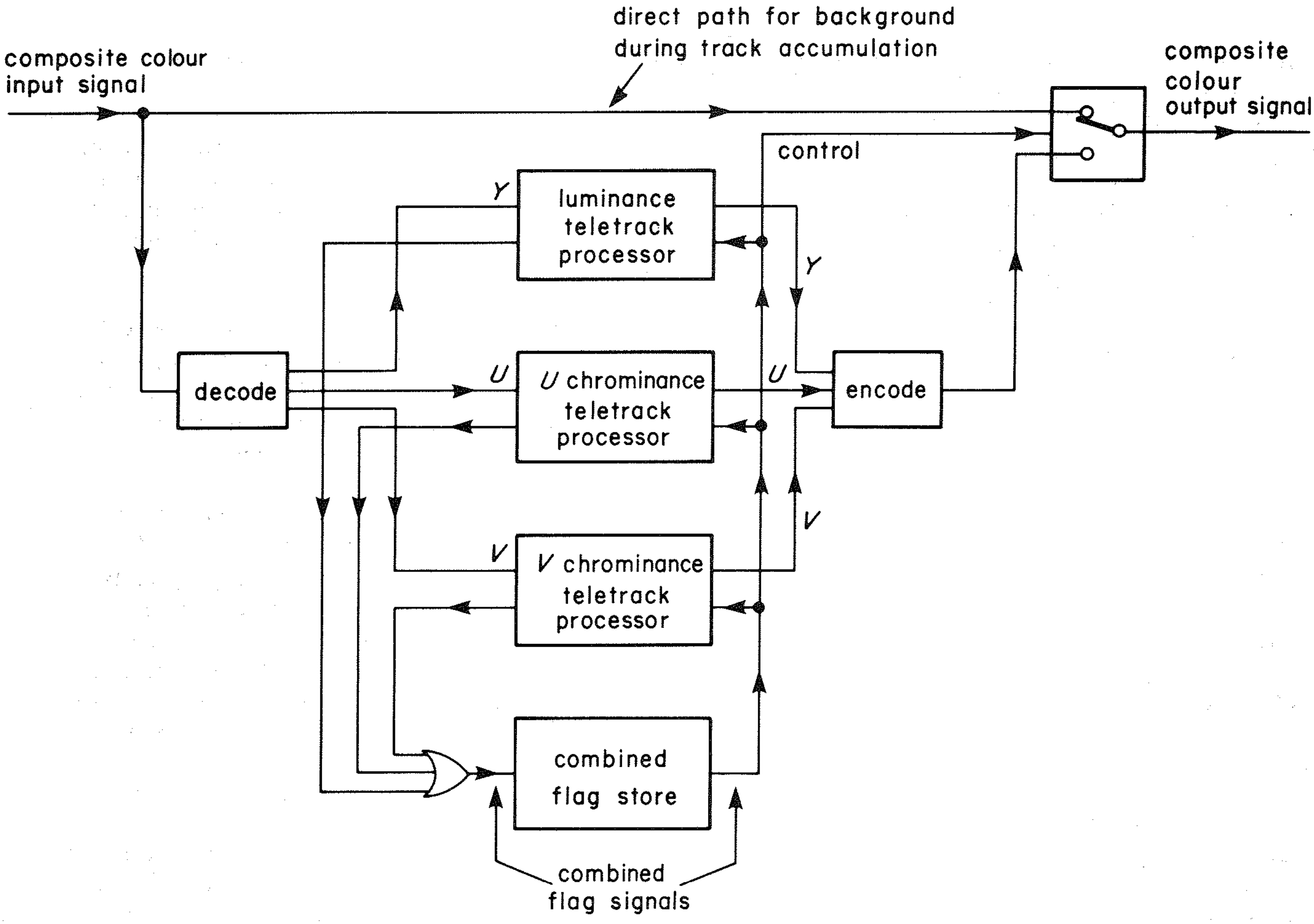
composite colour input signal
direct path for background during track accumulation
composite colour output signal
control
Y
luminance teletrack processor
Y
decode
U
U chrominance teletrack processor
U
encode
V
V chrominance teletrack processor
V
combined flag store
combined flag signals

Fig. 8 – A colour component Teletrack processor

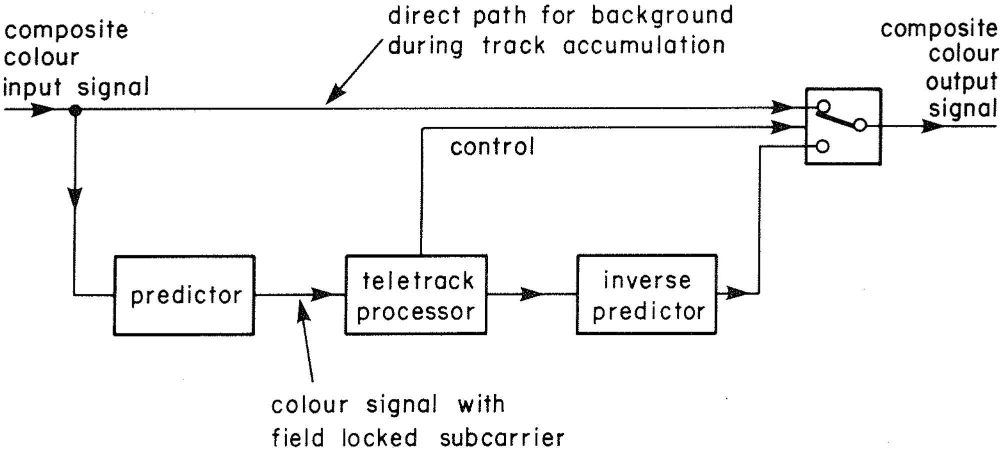
composite colour input signal
direct path for background during track accumulation
composite colour output signal
control
predictor
teletrack processor
inverse predictor
colour signal with field locked subcarrier

Fig. 9 – A composite signal Teletrack processor

The required capacity is therefore less than that needed for a signal decoding processor.

Impairments will again appear in frozen parts of the picture. These impairments occur because the two predictors take contributions from successive field lines to form a colour signal with the correct subcarrier phase. This amounts to vertical interpolation which in general reduces vertical chrominance resolution.

There will also be impairments to the luminance signal if the update rate is an odd number of fields. This occurs because of the necessity to perform vertical luminance interpolation to form the missing field lines and can be eliminated by restricting the update rate to multiples of two fields.

A direct bypass is included as before, to give a background free of impairments during the accumulation of a track.

6. Decaying images

A facility for displaying a decaying trail of images can give an artistically satisfying effect since it indicates the direction of motion of a moving object. This refinement is very effective for certain types of picture material, modern dance being a good example.

Accumulated images can be made to decay by substituting the circuit of Fig. 10 in the recirculating loops of the image stores of Fig. 6 or 7.

Switch 1 routes new images into the image store whenever a new flag occurs as in Fig. 6 and 7. Control signal 2 routes the output of the store either directly or via the attenuating circuit. When control signals 1 and 2 are both logic 0, the image will decay by a factor of $(1-a)$. This decay occurs because the input to the store is equal to $(1-a)$ times its last output plus a times the background signal appearing at the input A. The frozen images will therefore decay towards the current background signal.

The rate of decay is controlled by the value of a and the frequency of control signal 2, which should ideally be synchronous with the update signal. The closer that "a" is to zero, the longer the decay time.

Note that the flag signal should ideally be made to "decay" so that when a track has faded sufficiently to be barely visible, the associated recirculating flag disappears and allows current background to be routed to the output.

Frozen images will be extinguished automatically in the circuit of Fig. 7 provided that the flag is not recirculated, since the frozen, decaying images in the shared image and reference store will continue to create flags and therefore maintain themselves. When the frozen images have decayed sufficiently to cause no more flags, their positions will no longer be protected and they will disappear.

The flag signal in Fig. 6 must however be described by more than one digital 'bit'. The flag will therefore be set to a maximum number and will be decremented by one each time control signal 2 of Fig. 10 is made a logic 1. When the flag signal has reached zero, the flag is no longer recirculated thus terminating the track. A 5 bit flag will give 31 images before extinction, a 4 bit flag 15 and so on.

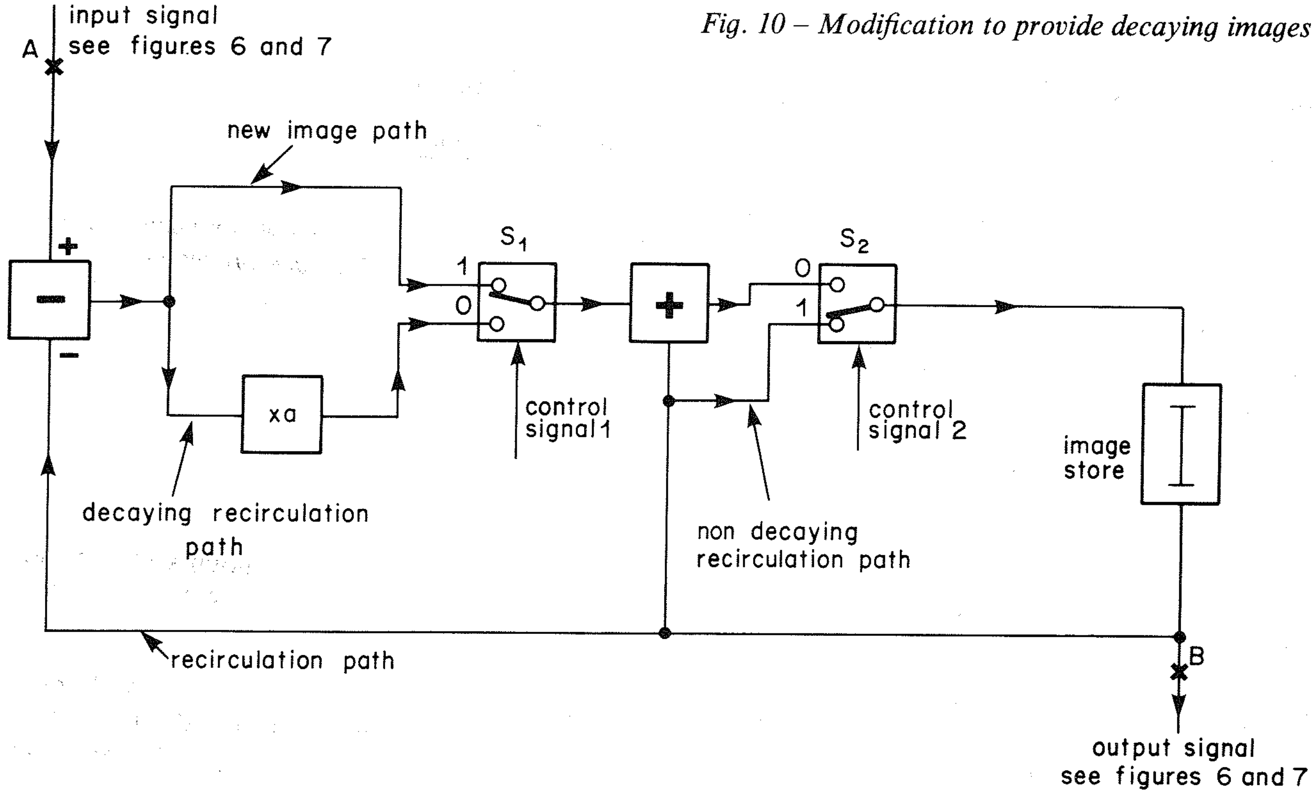

Fig. 10 – Modification to provide decaying images

An alternative is to compare the image store and reference store outputs in a second movement detector and terminate the flag when the two are sufficiently close in value, indicating that the frozen image has decayed to invisibility.

7. Conclusions

This report has described the theory of operation of a Teletrack processor and the factors involved in its design. Two preferred forms have been described in detail along with refinements and alternative modes of operation which would increase their versatility.

Many of the techniques used in the Teletrack processor have their origins in other work on digital video processing, notably video noise reduction. These techniques have since been used to provide a whole family of special effects, the scope of which is no longer limited by technology.

Teletrack was first used on BBC Television in 1980; it is available with the Quantel DPE 5001 Plus digital picture effects equipment, under licence from the BBC.

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